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EXPLANATORY NOTES ON THE MANOKWARI 1: 250 000 GEOLOGICAL SHEET, IRIAN JAYA

by

G.P. Robinson and Nana Ratman

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SUMMARY

The Manokwari 1:250 000 Sheet area lies between latitudes 0° and $1^{\circ}S$ and longitudes 133° 30'E and $135^{\circ}E$ in the northeastern extremity of the Kepala Burung region of Irian Jaya. Dissected mountainous landforms predominate in the southern half of the Sheet area, and are sharply demarcated from a wide alluvial plain.

In the Manokwari Sheet area, ten outcropping stratigraphic units ranging in age from Silurian to Holocene have been mapped. The stratigraphic thickness is possibly about 8000 m excluding the metamorphic rocks, which may be as much as 18 000 m thick. The Silurian to Devonian metamorphics (Kemum Formation) crop out in the southern mountainous region and consist mainly of fine-grained low-grade regionally metamorphosed sedimentary rocks. Along the length of the mountain front these rocks have been intruded and partially assimilated in places by a number of granodiorite, diorite, and gabbro bodies comprising the Wariki Granodiorite (Late Permian to Middle Triassic) and the Lembai Diorite (middle Miocene). Basalt and andesite flow breccia, tuff, and volcaniclastic sediments (Arfak Volcanics) of probable Oligocene to Miocene age occupy the southeastern corner of the Sheet area. The Arfak Volcanics may conformably overlie the subsurface Imskin Formation, a late Eocene to middle Miocene fine-grained marine limestone unit. Massive algal-foraminiferal biomicrite of Miocene age (Kais Formation) forms a number of elongate ridges to the northeast of the volcanics and unconformably overlies them. In the northeastern part of the Sheet area, soft well-bedded mudstone, siltstone, and sandstone (Befoor Formation) of late Miocene to Pleistocene age is unconformably overlain by Pleistocene raised reefs (Manokwari Limestone).

Surrounded by the western part of the extensive alluvial plain is a symmetrical mountain of Pliocene? agglomerate, Mount Berangan. Immediately to the south, at the edge of the mountain front, is an area of uplifted, dissected, and northerly tilted coarse alluvium and fanglomerate.

The Manokwari Sheet area is situated amid a complex array of crustal plates and subplates which have formed as a result of complicated interaction between the Australian and Pacific Plates and the island arcs and ocean basins of the Indonesian Archipelago. The two major structural elements within the Manokwari Sheet area, the Sorong and Ransiki Fault Zones, are continent/island-arc collision sutures which have subsequently undergone sinistral transcurrent faulting.

INTRODUCTION

The Manokwari 1:250 000 Sheet area lies between latitudes 0° and 1°S and longitudes 133°30'E and 135°E. The area lies in the northeastern extremity of the Kepala Burung region of Irian Jaya, and is administered from Manokwari, on the eastern mainland coast. The northern half of Numfoor Island is included in the southeastern part of the Sheet area.

The Sheet area may be reached by air or sea, either from Biak on an island 230 km to the east-southeast or from Sorong on the western part of the mainland (Fig. 1). There are daily air services from the large airstrip at Biak to Manokwari by DC3 or Twin Otter of Merpati Nusantara Airways. Coastal villages are supplied by small ships from Manokwari.

The only roads are around Manokwari; the longest extends south to Maruni village, from where Warmare village - about 20 km southwest of Manokwari is accessible by four-wheel-drive vehicle.

The coast may be traversed by small boat or canoe but none of the rivers is navigable. It is possible to land a helicopter on many beaches along the north coast and on numerous gravel banks extending along the length of the main rivers.

Less than 100 000 people live in the area, the largest concentration being around Manokwari township. Most villages are on the coast, and each contains up to a few hundred people. About 2000 people, many of them Javanese, have been resettled at Warmare village under a government transmigration scheme.

The indigenous population lives mainly by subsistence agriculture, supplemented by a small amount of fishing. Some cash crops (peanuts, copra) are grown in the Manokwari and Warmare areas. In the Manokwari area, additional income comes from a small ship-repair and construction yard and a sawmill, both owned by the Government.

The main climatic characteristics of the Manokwari Sheet area are: uniformly high temperatures throughout the year; high humidity; heavy annual rainfall; and a seasonal variation caused by the alternation of the southeast trade winds and the northwest monsoon. During the months June to September the area receives light rainfall brought by the southeast trade winds. From November to March the northwest monsoon brings heavy rain to the whole north coast of Kepala Burung.

Most of the area is covered by primary rainforest with some narrow belts of natural grasslands near the braided lower reaches of the larger rivers. Man-induced grasslands and secondary rainforest occur around Warmare and Manokwari.

Base maps and aerial photographs

A 1:250 000 topographic sheet (Joint Operations Graphic, Air) of the Manokwari Sheet area was compiled in 1967 by the United States Army Map Service, Corps of Engineers. The area is covered by poorly controlled maps at a scale of 1:20 000 produced by the United States Army during 1945 from vertical and oblique photography. Complete aerial photographic coverage of the Manokwari Sheet area is available. In addition to the American photography, 1:20 000 vertical photographs taken by KLM/Aerocarto were available in 1976; these were used during field-work. Kepala Burung was rephotographed by the RAAF in late 1976 at a scale of 1:100 000 using Wild RC 10 cameras with superwide-angle lenses.

History of investigations

The first map showing the general geology (scale 1:1 500 000) of Irian Jaya including the Manokwari Sheet area was published in Visser & Hermes (1962). An economic geological investigation of the northeastern part of Kepala Burung was made between 1959 and 1962 by the 'Foundation

Geological Investigation Netherlands New Guinea', and a lengthy report was published (d'Audretsch, Kluiving, & Oudemands, 1966). This report includes geological compilation maps at scales of 1:100 000 and 1:250 000.

These notes and the accompanying map are based on fieldwork by G.P. Robinson, N. Ratman, D.S. Hutchison, M. Masria, D.S. Trail, Kastowo, H. Sumadirdja, and P.E. Pieters in September and October 1976. This work was the initial part of an ongoing mapping program which will be carried out under the Australian Development Assistance Bureau as an Indonesian-Australian integrated geological survey of Irian Jaya. The 1976 fieldwork in the Kepala Burung involved the following geologists from the Geological Survey of Indonesia (GSI): H. Sumadirdja (party leader) N. Ratman, Kastowo, and M. Masria. The Bureau of Mineral Resources of Australia (BMR) team consisted of D.S. Trail (party leader) R.J. Ryburn, G.P. Robinson, P.E. Pieters, and D.S. Hutchison.

PHYSIOGRAPHY

The area has been divided into seven physiographic units (Fig. 1).

Dissected mountainous landforms

The southwestern part of the Sheet area is mountainous and deeply dissected by large braided rivers which flow to the north coast. Between the largest of these two rivers, the Waramoi and Waryori, is the highest point in the area, Mount Itsjwei, at about 2650 m. To the west of the Waramoi River the mountainous landforms extend to within 8 km of the coast. The abrupt southeasterly-trending front of the mountain belt crosses the southern edge of the Sheet area about 7 km west of Maruni village.

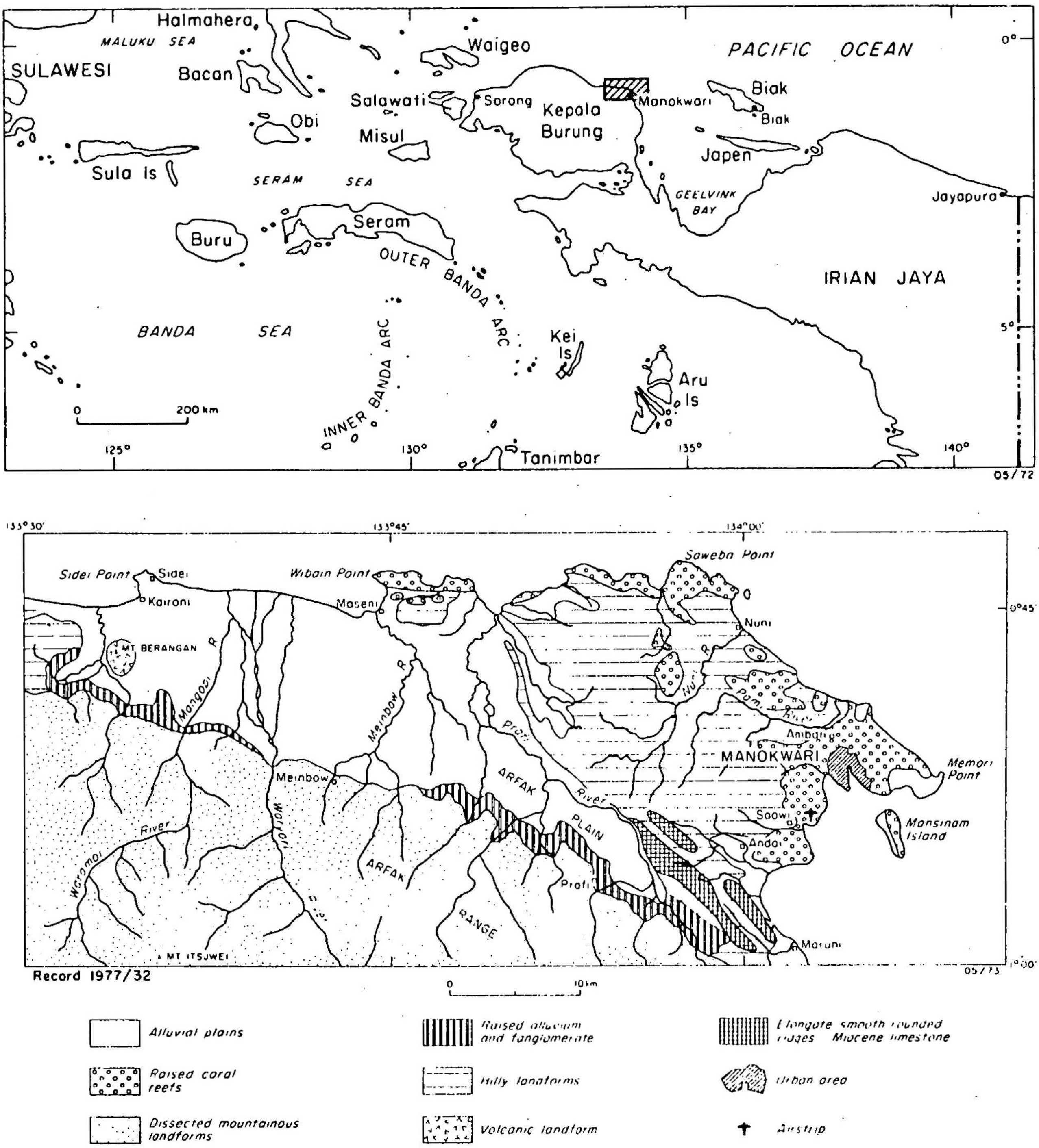

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Fig. 1 Location and Physiography diagram

Alluvial plain

To the north of the mountain belt and sharply demarcated from it is a large alluvial plain zone extending to the coast. The alluvial plain is over 20 km wide east of the Prafi River, and merges eastwards into hilly landforms; it narrows to only 8 km at the western edge of the Sheet area. Large gravel banks have formed along most of the rivers crossing the plain.

Hilly landforms

In the northeastern part of the Sheet area, hilly terrain of low relief is characterised by rounded ridges and small streams in which gravel banks are absent or very small. The drainage of this terrain contrasts markedly with that in the dissected mountainous landforms and the alluvial plain, where large overloaded streams flow north from the high rugged region south of the Sheet area.

Raised coral reefs

To the north and east of the hilly landforms the coast is lined with coral reefs up to about 150 m high. Isolated reefs, elevated up to about 150 m, form smooth hills northwest of Manokwari.

Miocene limestone ridges

The Miocene limestone topography is confined to the southeastern part of the Sheet area, and consists of several parallel elongate and smooth-textured ridges the highest of which is elevated up to about 1000 m above sea level.

Raised alluvium and fanglomerate flatirons

Between the Wariki* and Waryori River and between the Menejewi River and the east coast immediately to the north of the mountain front are a number of northerly dipping flatirons of uplifted and dissected coarse alluvium and fanglomerate.

Volcanic landform

In the far northwestern part of the Sheet area is a remarkably symmetrical dome-shaped mountain rising to a height of almost 600 m above the alluvial plain. The mountain consists of soft, poorly sorted andesitic agglomerate

STRATIGRAPHY

In the Manokwari Sheet area ten outcropping stratigraphic units ranging in age from Silurian to Holocene have been mapped. The stratigraphic thickness is possibly about 800 m excluding the metamorphic rocks which may be as much as 18 000 m thick. The Silurian to Devonian metamorphics (Kemum Formation) crop out in the southern mountainous region and consist mainly of fine-grained low-grade regionally metamorphosed sedimentary rocks. Along the length of the mountain front these rocks have been intruded and partially assimilated in places by a number of granodiorite, diorite, and gabbro bodies comprising the Wariki Granodiorite (new name; Late Permian to Middle Triassic) and the Lembai Diorite (new name; middle Miocene). Basalt and andesite flow breccia,

*The map shows two Wariki Rivers: one a tributary of the Kasi River in the west and the other a tributary of the Waryori River to the east. All references to the Wariki River in the text are to the one in the west.

tuff, and volcaniclastic sediments (Arfak Volcanics; new name) of probable Oligocene to Miocene age occupy the southeastern corner of the Sheet area. The Arfak Volcanics may conformably overlie the subsurface Imskin Formation, a late Eocene to middle Miocene fine-grained marine limestone unit (Visser & Hermes 1962, Rahardjo, 1975). Massive algal-foraminiferal biomicrite of Miocene age (Kais Formation) forms a number of elongate ridges to the northeast of the volcanics and probably unconformably overlies them. In the northeastern part of the Sheet area, soft well-bedded mudstone, siltstone, and sandstone (Befoor Formation) of late Miocene to Pleistocene age is unconformably overlain by Pleistocene raised reefs (Manokwari Limestone; new name). Surrounded by the western part of the extensive alluvial plain is a symmetrical mountain (Mount Berangan) of Pliocene? volcanics (Berangan Agglomerate; new name). Immediately to the south, at the edge of the mountain front, is an area of uplifted, dissected, and northerly tilted coarse alluvium and fanglomerate.

Kemum Formation

The Kemum Formation forms the deeply dissected mountainous landforms drained by large braided rivers. The main lithologies are slate, phyllite, siliceous argillite, metachert, quartzite, mica schist, and (rarely) metamicromonzonite. Two broad lithological trends in the Kemum Formation may be distinguished within the Sheet area: the rocks are more siliceous to the west, whereas the grade of metamorphism is higher to the east.

In the west the main rock types in order of abundance are quartzite, siliceous argillite (Fig. 2), metachert, slate, and phyllite. The quartzite, much of which is finely recrystallised, is usually dark greenish black* to medium grey on freshly broken surfaces, but very much

* All colours are based on the Geological Society of America rock colour chart.

lighter on weathered faces. Aggregates of chloritised ferromagnesian minerals (1-2 mm long) form up to 40 percent of the greenish quartzite and up to 1 percent finely disseminated authigenic pyrite is present in the darker varieties. Most of the quartzite is coarsely bedded (1-3 m), but lighter and darker quartzite layers 2-10 cm thick alternate in a few places (Fig. 3). Quartzite breccia with clasts up to several centimetres across is present in one or two localities. The siliceous argillite, slate, and phyllite are generally greenish black to medium dark grey, and usually have more distinct and finer bedding than the quartzite and metachert. Sandy layers 2 cm thick separated by argillite layers up to 10 cm thick give clearly distinguishable bedding to some of the slate and phyllite.

In the central part of the Sheet area (lower Waryori River, Meinbow, Ismariam, and Menejewi Rivers) phyllite, siliceous argillite, slate, and quartzite are the main lithologies in order of abundance. The phyllite is normally massive and varies in colour on fresh surfaces from greenish black or medium grey to olive-grey; weathered surfaces are much lighter. Small-scale slump structures are present in a few places in the siliceous argillite, which is usually greyish black to medium grey, well-bedded (beds 2cm-0.5 m thick), and contains about 1 percent authigenic pyrite aggregates up to 2 cm across. The quartzite is greenish grey to light olive-grey in most places, and is usually finely recrystallised (0.5-1 mm) and massive, with finely disseminated authigenic pyrite (less than 1 mm, less than 1 percent). Medium light grey to light olive-grey metagreywacke crops out in places; it contains up to 50 percent ferromagnesian minerals and has a siliceous cement.

Towards the east (Ibarregah River) dark greenish grey or brownish black to olive black mica schist is the predominant lithology. It generally contains about 60 percent biotite flakes ranging in size from 0.125-0.5 mm. Some medium grey biotite schist contains biotite

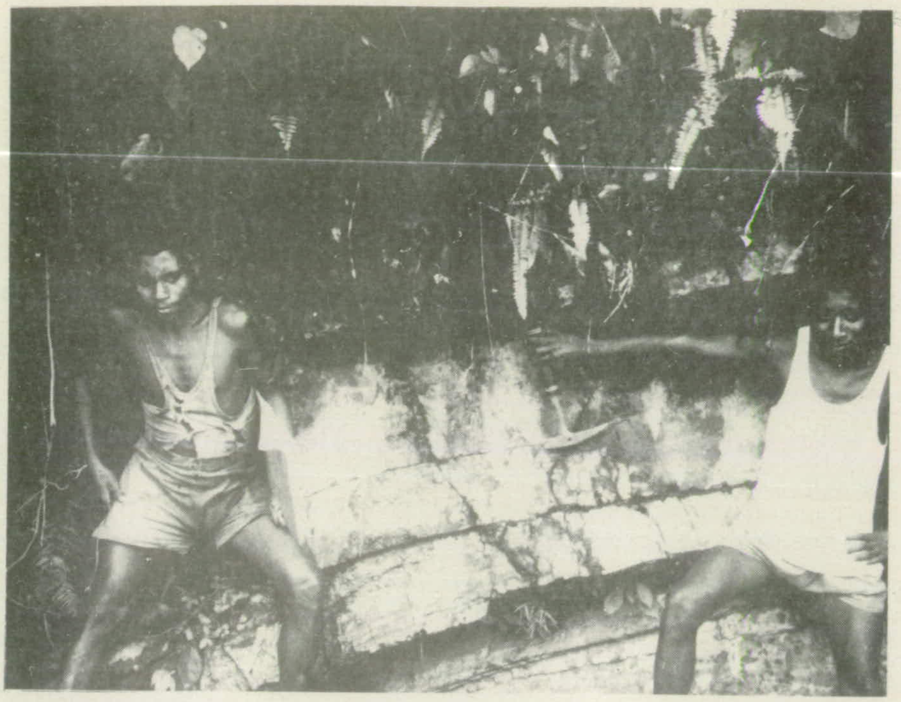


Figure 2. Well bedded siliceous argillite of the Kemum Formation in the Waryori River.

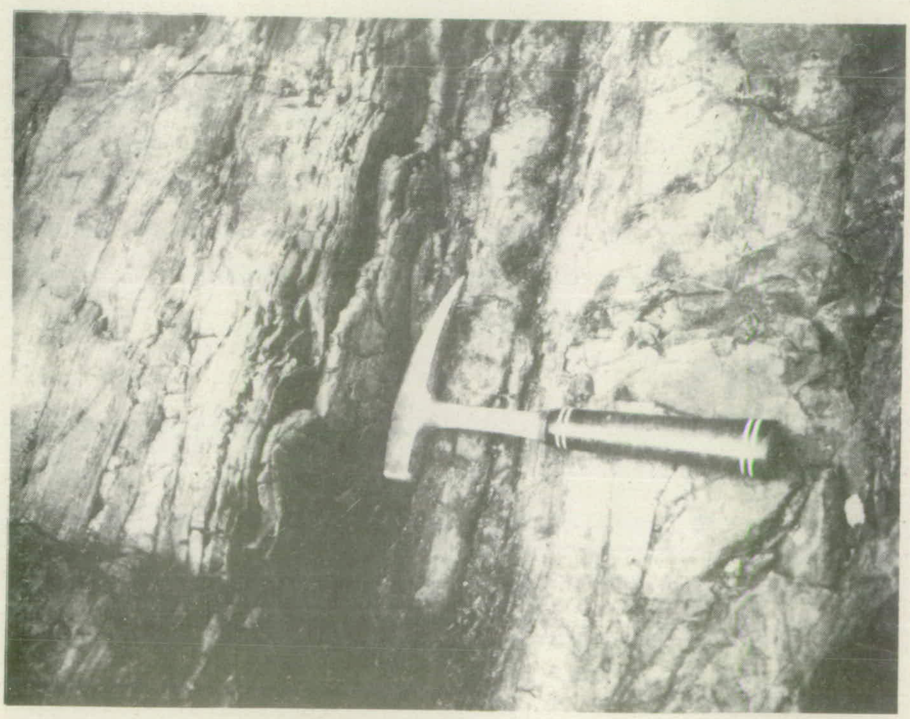


Figure 3. Well bedded quartzite with alternating lighter and darker layers within the Kemum Formation in the Waramoi River.

crystals in aggregates 3 cm across and forming up to 20 percent of the rock. Some specimens contain light irregular spongey porphyroblasts of andalusite 1 cm across in layers forming up to 50 percent of the rock. These mica schists generally contain abundant quartz and muscovite, as well as small amounts of hornblende, calcic plagioclase, tourmaline, and carbonate. Metachert and coarsely bedded, dark grey to olive black, medium to fine siliceous metagreywacke is exposed at a few localities. The metachert is olive black in colour and contains 20 percent very finely disseminated pyrite.

Metamicromonzonite is a rare rock type in the Kemum Formation within the Manokwari Sheet area. It is dark grey, greenish black, or olive black on fresh surfaces, holocrystalline (0.5-1 mm), and contains ferromagnesian minerals (mainly biotite) and nearly 40 percent plagioclase and K feldspar; some specimens contain less than 1 percent pyrite in aggregates 1 mm across. The one dyke of metamicromonzonite observed in the Sheet area is in the Ibarregah River and is not more than 2 m thick. Calcareous slate crops out in two places in the Ibarregah River. The rock is dark grey to greyish black in colour and in places it is strongly foliated. The less foliated rock is strongly veined by calcite. These two large outcrops in the Ibarregah River, together with one small outcrop of calcareous slate in the Menejewi River, constitute the only known occurrences of calcareous rocks in the Kemum Formation within the Manokwari Sheet area.

The Kemum Formation in the Manokwari Sheet area is estimated to be up to 18 000 m thick, but this estimate may include parts of the sequence repeated by faulting. In the Ransiki Sheet area, immediately to the south of the Manokwari Sheet area, Pertamina, the national oil company of Indonesia, measured a thickness of between 1515 and 2160 m within the Kemum Formation (Rahardjo, 1975).

The fine grainsize of the Kemum Formation, together with the presence of chert, suggests that the unit was deposited in a deep sea. The unit is unconformably overlain by older alluvium/fanglomerate. Its relation to underlying rocks is unknown. It is intruded by the Late

Permian to Middle Triassic Wariki Granodiorite, which has caused some thermal metamorphism and minor hydrothermal alteration. Near the contact with the middle Miocene Lembai Diorite, it has been partly assimilated. The age of the Kemum Formation in the type locality (Kemum River, central Kepala Burung) is Silurian (Lower Gothlandian); this age is based on the occurrence of Monograptus turriculatus and Monograptus marri (Visser & Hermes, 1962). In the Ransiki Sheet area (Bintuni Basin) the age has been determined as Devonian, based on the occurrence of the two ostracod genera Richterina sp. and Acanthoscapha sp. (Rahardjo, 1975).

Arfak Volcanics

In the far southeastern corner of the Manokwari Sheet area the Arfak Volcanics occupy an area of about 20 km^2. The area includes part of the far northern foothills of the rugged Arfak Range to the south.

The Arfak Volcanics consist of submarine andesitic to basaltic lava breccia, and - predominating in the Manokwari Sheet area - volcaniclastic sediments formed by the breaking up of the lava flows as they descended the submarine slopes. Many of the rocks could be termed hyalocalastites. Rubble slides, paraconglomerate, and associated turbidite deposits were formed by the movement of lava away from the southeasterly trending axis of the Arfak mountain chain. Tuff, interbedded with the lava breccia and derived sediments, probably originated from subaerial and submarine volcanic centres, and peperite - formed by the eruption of lava through wet sediment (Carozzi, 1960) - is probably also present. The unit possibly has a maximum thickness of about 3000 m in the Sheet area.

The Arfak Volcanics possibly conformably overlie the Imskin Formation and are unconformably overlain by the Kais Formation. The age of the Arfak Volcanics is unknown. They closely resemble the late Oligocene to early Miocene Finisterre Volcanics of northern Papua New Guinea. The Arfak Volcanics are partly synonymous with the Auwewa Volcanics of d'Audretsch and others (1966). The Auwewa Volcanics were defined by these authors as including all volcanic units in Kepala Burung ranging in age from late Eocene to early Miocene.

Kais Formation

The Kais Formation forms a number of elongate southeasterly trending ridges in the southeastern part of the Sheet area. It consists mainly of massive yellowish grey to white algal-foraminiferal biomicrite, which is resistant, non-porous, and brittle. The unit is probably about 500 m thick in the Manokwari Sheet area, and may have formed in a fringing or barrier reef environment. It unconformably overlies the Arfak Volcanics, and is unconformably overlain by the Befoor Formation. Assemblages of larger foraminifera suggest an early to middle Miocene age.

Befoor Formation

The Befoor Formation underlies the hilly landforms in the northeastern part of the Sheet area. The main lithologies are sandstone, siltstone, mudstone, and minor conglomerate. Most of the sediments are well-bedded (Fig. 4), and current lamination and, less commonly, larger-scale cross-bedding are evident in places. The sandstone is usually medium-grained (0.25÷0.5 mm), light olive-grey, soft, friable, and either non-calcareous or weakly calcareous. The sand grains are mainly quartz, but most of the sandstone specimens contain about 10 percent volcanic detritus. All specimens are very poorly sorted and porous. Interbedded with the sandstone in many outcrops are siltstone, mudstone, and, in places, conglomerate. The siltstone is generally dark greenish grey or light olive-grey to medium dark grey and contains up to 15 percent muscovite flakes. Like the sandstone, the siltstone is usually soft, friable, porous, and either non-calcareous or weakly calcareous. The dark greenish grey to medium bluish grey mudstone is silty and commonly contains abundant foraminifera.

Apart from the mudstone, the sequence examined is unfossiliferous, with the exception of one outcrop in the Nuni River. This consists of soft and friable very fine sandstone and silty mudstone with resistant medium to coarse calcarenite beds 3 to 6 cm thick spaced at intervals of about 10 cm. The sandstone is light olive grey, calcareous, and porous, and the calcarenite is yellowish grey to greyish yellow with grains ranging from 0.25 to 1.0 mm across. Bivalves occur throughout the outcrop, and current bedding is evident.

The Befoor Formation has a maximum thickness of probably about 1600 m. It was probably deposited in a shallow-water marine to estuarine environment of deposition whose source of sediments was the Kemum Formation regional metamorphics to the southwest and, to a much lesser extent, the Arfak Volcanics to the south. The Befoor Formation unconformably overlies Kais Formation and the Arfak Volcanics, and is unconformably overlain by the Manokwari Limestone. Assemblages of planktonic foraminifera give a late Miocene to Pleistocene age for the Befoor Formation.

Manokwari Limestone

Raised reef limestone around the coastal areas near Manokwari capping low hills in the northeastern part of the Sheet area have been grouped within the Manokwari Limestone. Massive porous resistant algal-foraminiferal biomicrite (Fig. 5), calcirudite and calcarenite are the main rock types. Most of the limestone is greyish yellow to white, and in places contains 20-30 percent dusky yellow subangular to subrounded clasts of fine calcarenite and calcilutite up to 10 cm across. In

Figure 4. Well-bedded fine to very fine sandstone, siltstone, and mudstone of the Befoor Formation in the lower reaches of the Pami River.

Figure 5. Boulder of massive porous algal-foraminiferal biomicrite of the Manokwari Limestone in the lower reaches of the Pami River.

places such pure reef limestone containing algae, foraminifera, and coral has been heavily contaminated by terrigenous detritus - for example, at Sidei, the Manokwari Limestone contains a poorly sorted crudely bedded to current-bedded conglomerate containing well-rounded clasts, 2-3 cm across, of low-grade regional metamorphics and granite in a highly calcareous sand-size matrix. The Manokwari Limestone is probably about 800 m thick. It is thought to have formed as fringing reef complexes that were contaminated by terrigenous detritus in places and subsequently uplifted. The unit unconformably overlies the Befoor Formation. Its age is Pleistocene.

Berangan Agglomerate

Near the junction of the Kasi and Wariki Rivers in the far northwestern part of the Sheet area is the remarkable symmetrical Mount Berangan, which consists of basaltic to andesitic agglomerate. On the western flank of the humped mountain, massive poorly sorted basaltic agglomerate with clasts up to 10 cm across is exposed in a cliff section 50 m high. The clasts form about 50 percent of the rock and are more resistant than the remainder of the agglomerate, which consists of angular very coarse sand-size basaltic and andesitic fragments. Porphyritic scoriaceous low-silica andesite with 2 percent plagioclase phenocrysts 3 mm long is the most common clast type. The porous nature of this rock implies that it has not been buried.

Explosive volcanic activity has probably given rise to the Berangan Agglomerate, which is about 900 m thick though of very limited lateral extent. The morphology of the mountain suggests a Pliocene age. Relations with underlying rocks are unknown. D'Audretsch and others (1966) placed these rocks within the Auwewa Formation (late Eocene-early Miocene).

Raised alluvium and fanglomerate

Between the Wariki and Waryori Rivers in the western part of the area, and between the Menejewi River and the east coast, is a sequence of coarse alluvium and fanglomerate exposed in a number of dissected northerly dipping flatirons. Cliffs up to 25 m high along the mountain front in these areas consist of massive very poorly sorted conglomerate and boulder beds of an overall reddish brown colour (Fig. 6). Interbedded with these coarse deposits on the ridge between the Wariki and Mangopi Rivers is well-bedded dark yellowish orange clay; each bed is laterally persistent and about 2 m thick. Clasts of low-grade regional metamorphics of the Kemum Formation predominate in the coarser deposits.

The raised alluvium and fanglomerate have an estimated total thickness of about 400 m. They are thickest between the Wariki and Mangopi Rivers, and abruptly thin to the east, west, and north, forming a wedge-shaped body at the break in slope between the mountains and the alluvial plain. They represent alluvial fan deposits which accumulated along the mountain front and whose northerly primary depositional dip was accentuated by uplift and northerly tilting. They unconformably overlie the Kemum Formation, Arfak Volcanics, and Kais Formation, and nonconformably overlie the Wariki Granodiorite and Lembai Diorite. The unit is probably Pleistocene to Holocene in age.

<u>Alluvial and beach deposits</u>

A large alluvial plain lies to the north of the dissected mountainous landforms. It extends from east of the Prafi River, where it is over 20 km wide, to the western edge of the Sheet area, where it narrows to only 8 km. The alluvial deposits consist of coarse gravel exposed along the large braided river courses; these deposits appear to have the same composition as the raised alluvium and fanglomerate to the south. In general the alluvial deposits become finer-grained towards the north, away from the mountain zone. In the lower reaches of the Waryori River are some areas of fine silt and mud. Along the coast, particularly between Sidei and the mouth of the Waryori River, are beach deposits consisting mainly of coarse gravel. Sand occurs along the beach west of Sidei. River terraces have formed in coarse alluvium along the lower reaches of the Waryori and Mangopi Rivers.

The alluvial deposits appear to truncate and partly overlie the northern edge of the older raised alluvium and fanglomerate. The overall configuration of the alluvial belt suggests that the deposits have accumulated in a shallow graben between the dissected mountainous landforms in the southern part of the Sheet area and the hilly landforms east of the Prafi River. The deposits may be up to 400 m thick in the central part of this graben.

Wariki Granodiorite

The Wariki Granodiorite is best exposed in the upper reaches of the Wariki River, but also occurs in the Waramoi, Waryori, Meinbow, Ismariam, Menejewi, and Ibarregah Rivers and in tributaries of the Waryori River. The topographic expression of the granodiorite is not clearly distinguishable from the Kemum Formation on aerial photographs.

In the Wariki River the granodiorite is even-grained (2-4 mm) and has a planar fabric caused by a rough planar segregation of feldspar and ferromagnesian minerals; some hand specimens of the rock contain up to 50 percent biotite. Very coarse (4 mm) light grey granite crops out in the Waryori River, where the rock contains about 30 percent biotite and 20 percent quartz, and tonalite forms part of the intrusive body in the lower reaches of the Waramoi River. The granodiorite in the Meinbow and Waryori Rivers contain xenoliths. These are numerous in the Meinbow River, where they comprise fine-grained dark intermediate plutonic rocks which may be cognate xenoliths representing the earlier marginal differentiates of the rock body. One greenish black xenolith in a western tributary of the Waryori River is 1 m long and 0.5 m across, and has a joint or fault contact with the granite on one side; it is fine-grained (0.5-1 mm) with about 60 percent hornblende and about 1 percent finely disseminated aggregates of pyrite less than 1 mm across. In the Ibarregah River the granodiorite is very coarse with about 30 percent interstitial quartz from 1 mm to 1 cm across.

Numerous pegmatite dykes cut the Kemum Formation on the margin of the Wariki Granodiorite in the Ibarregah River. Many of the dykes and sills are from 0.5 to 1 m thick and some are bifurcated (Fig. 7). They

Figure 6. Raised alluvium and fanglomerate consisting of massive very poorly sorted conglomerate and boulder beds in the lower reaches of the Wariki River.

Figure 7. Bifurcated pegmatite dyke intruding mica schist of the Kemum Formation in the upper reaches of the Ibarregah River.

are generally very light grey to white, and have clearly defined margins and a grainsize of between 1-2 cm. Hornblende crystals, commonly 0.5 cm across, form about 5 percent of the pegmatite; muscovite flakes (1 cm) form 15-20 percent; and the remainder consists mainly of sodic plagioclase and quartz.

The granodiorite was probably emplaced as a highly viscous magma, but was capable of at least some flow as indicated by the planar fabric of the partly segregated and oriented crystals in the Wariki River. Cognate xenoliths in the Meinbow and Waryori Rivers indicate at least one remobilisation. Post-consolidation shear is evidenced truncating pegmatite dykes in many localities and at the margin of the large xenolith in the Waryori River. Thermal metamorphism and minor hydrothermal alteration occur in the Kemum Formation in the contact zone in both the Waryori and Meinbow Rivers. Finely disseminated iron sulphides are present in the metamorphics but the majority of these are probably authigenic. K-Ar analyses of three samples from the Wariki Granodiorite indicate ages ranging from Late Permian to Middle Triassic (Appendix III).

Lembai Diorite

The Lembai Diorite is exposed in the upper reaches of the Lembai River and in the lower reaches of the Ibarregah River in the lower reaches of the Ibarregah River in the southeastern part of the area. Like the Wariki Granodiorite its topographic expression does not differ appreciably from the surrounding Kemum Formation. The diorite is usually between medium dark grey and olive-grey on fresh surfaces. It is holocrystalline, even-grained, commonly coarse (5 mm), and contains up to 50 percent ferromagnesian minerals. In places it grades into gabbro. Numerous acidic veins (Fig. 8) and dykes throughout the diorite show considerable variation in overall shape, sharpness of contacts, texture, and composition, both between themselves and along their lengths. Blended contacts with considerable digestion and hybridisation of the surrounding diorite, and plastically deformed veins, suggest a highly mobile magma during and after the time of the late hydrothermal

Figure 8. Intersecting acidic veins within the Lembai Diorite in the upper reaches of the Lembai River.

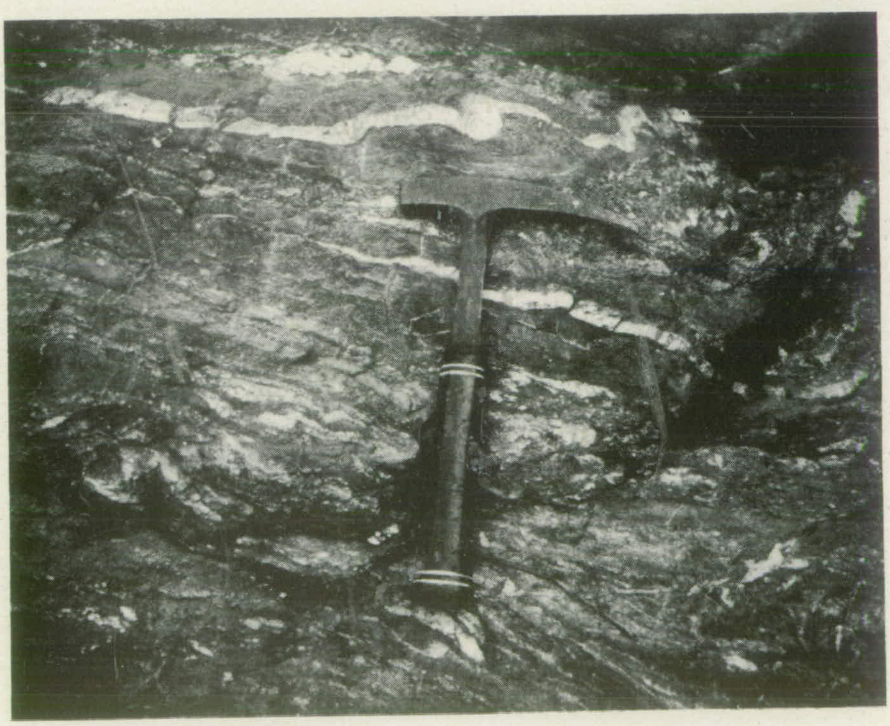


Figure 9. Schist of the Kemum Formation partly assimilated by the Lembai Diorite in the lower reaches of the Ibarregah River.

emplacement. At the margin of the Lembai Diorite in the lower reaches of the Ibarregah River, large outcrops of schist and phyllite of the Kemum Formation show various stages of complete replacement by diorite (Fig. 9). In addition to the various assimilation textures and structures in this locality, planar fabric probably caused by almost complete assimilation of the metamorphics by the diorite is well shown in the lower reaches of the Lembai River.

A K-Ar analysis of a sample from the Lembai Diorite indicates a middle Miocene age (Appendix III).

TECTONIC SETTING

The Manokwari Sheet area is situated amid a complex array of crustal plates and subplates (Fig. 10). Fundamentally the present plate configuration is the result of complicated interaction between the northerly moving Australian Plate, the west-northwesterly moving Pacific Plate, and the island arcs and ocean basins of the Indonesian Archipelago. Thus the major structural features, including those which are no longer active, must be thought of in terms of constantly changing plate and island-arc interaction. The Ransiki Fault Zone and the Sorong Fault Zone, which converge and meet in the Manokwari Sheet area, may be understood in this light: both are continent/island-arc collision sutures which have subsequently undergone sinistral transcurrent faulting. The Ransiki Fault Zone represents a continent/island-arc Miocene collision suture between the essentially metamorphic and granitic continental rocks of Kepala Burung with the Oligocene to Miocene island-arc volcanics of the Arfak Mountains. The Ransiki Fault may represent a sinistral transcurrent fault, formerly easterly trending, that formed before Kepala Burung was rotated clockwise. The Sorong Fault Zone probably originated in the same way - that is, as a sinistral transcurrent fault representing a continent/island-arc collision suture - after Kepala Burung had rotated in a clockwise direction, thus imparting a south-easterly trend to the Ransiki Fault Zone.

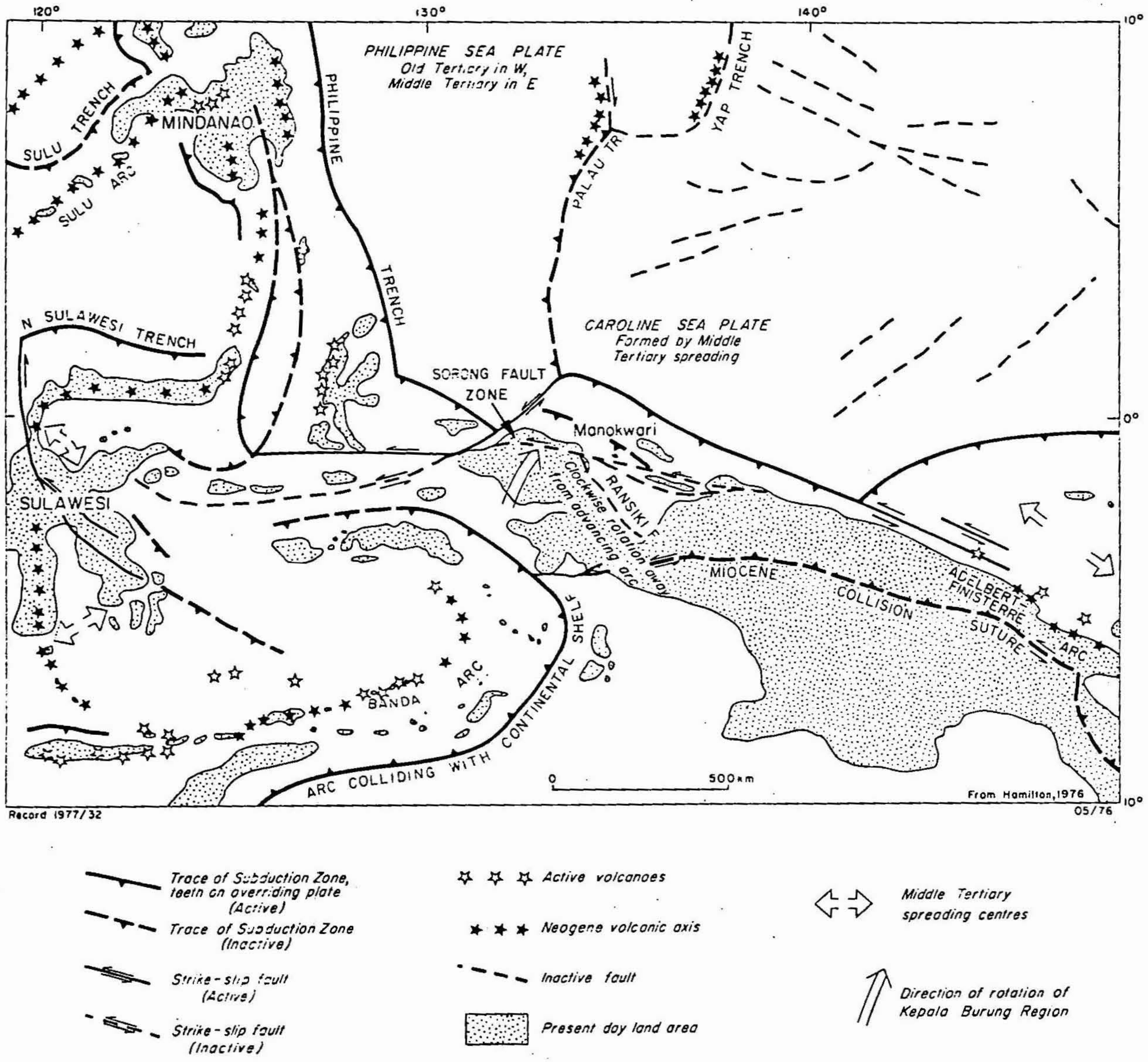


Fig. 10 Tectonic setting of the Manokwari area

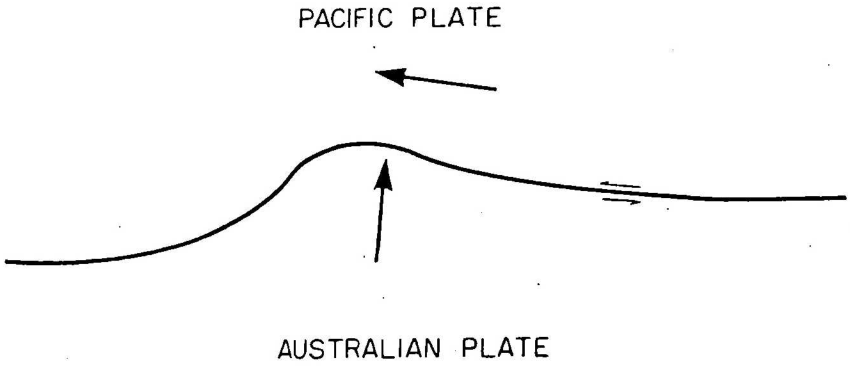
The development of the Ransiki Fault Zone, the clockwise rotation of Kepala Burung, and the formation of the Sorong Fault Zone truncating the Ransiki Fault Zone are shown diagramatically in Figure 11. In this hypothetical structural development of the Kepala Burung region, two factors might have contributed to bring about clockwise rotation: (1) westerly (sinistral) movement of northern Irian Jaya and Papua New Guinea along numerous parallel transcurrent faults would have forced the southwestern end of Kepala Burung against the Banda Arc; and (2) possible spreading in the Banda Sea would have increased the stresses between Kepala Burung and the Banda Arc. Although there is as yet no definite evidence for crustal spreading in the Banda Sea, the area is the site of an undation (and, consequently, as the result of gravity, a spreading centre) according to van Bemmelen (1949). W. Hamilton (USGS, personal communication, 1977) considers it likely that spreading has taken place in this area.

STRUCTURE

In the Manokwari Sheet area the Sorong Fault Zone is topographically expressed as an abrupt change in slope between the dissected mountainous landforms to the south and the alluvial plain to the north. This change in slope coincides with a west-northwesterly line from the Masi River to a point 8 km south of the coast on the western border of the Sheet area. The Ransiki Fault Zone forms a south-southeasterly trending fault-line valley extending from the Masi River to the Ransiki River (southeastern Ransiki Sheet area). In the northern part of the Ransiki Sheet area, the Ransiki Fault Zone is represented by a long, narrow, linear zone of strongly sheared gabbro and diorite intrusions and steep to vertical resistant Kais Formation limestone; this shear zone separates strongly sheared and slickensided low-grade metamorphics of the Kemum Formation to the west from sheared and slickensided Arfak Volcanics to the east.

1

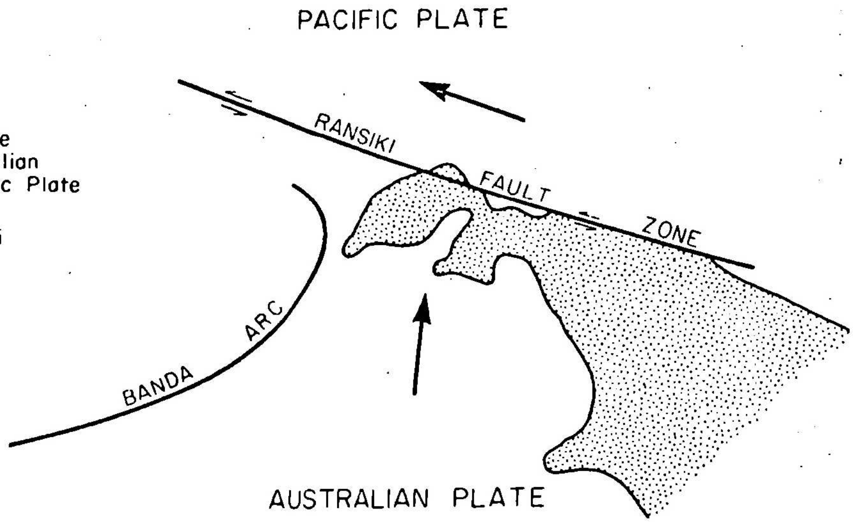
Development of early Australian-Pacific Plate collision suture



2

(a) Increased bending leading to ultimate rupturing of collision suture by continued N movement of Australian Plate and NW movement of Pacific Plate

(b) NE part of suture becomes Ransiki Fault Zone ; SW part becomes Banda Arc



3

(a) Sinistral movements in N Papua New Guinea and Irian Jaya force Kepala Burung region against Banda Arc

(b) Clockwise rotation of Kepala Burung and folding in SE part

(c) Continued bending of Banda Arc by N and NW stresses

(d) Development of Sorong Fault Zone truncating Ransiki Fault Zone

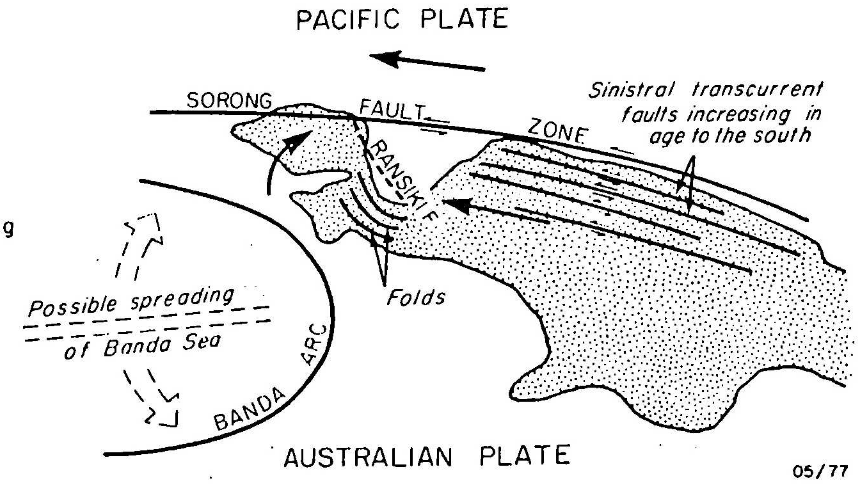


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Fig. 11 Hypothetical structural development of the Kepala Burung region

Figure 12. Strongly jointed fine to very fine metagreywacke sandstone of the Kemum Formation in the lower reaches of the Waryori River

Figure 13. Conjugate shear joints in mica schist of the Kemum Formation in the upper reaches of the Ibarregah River.

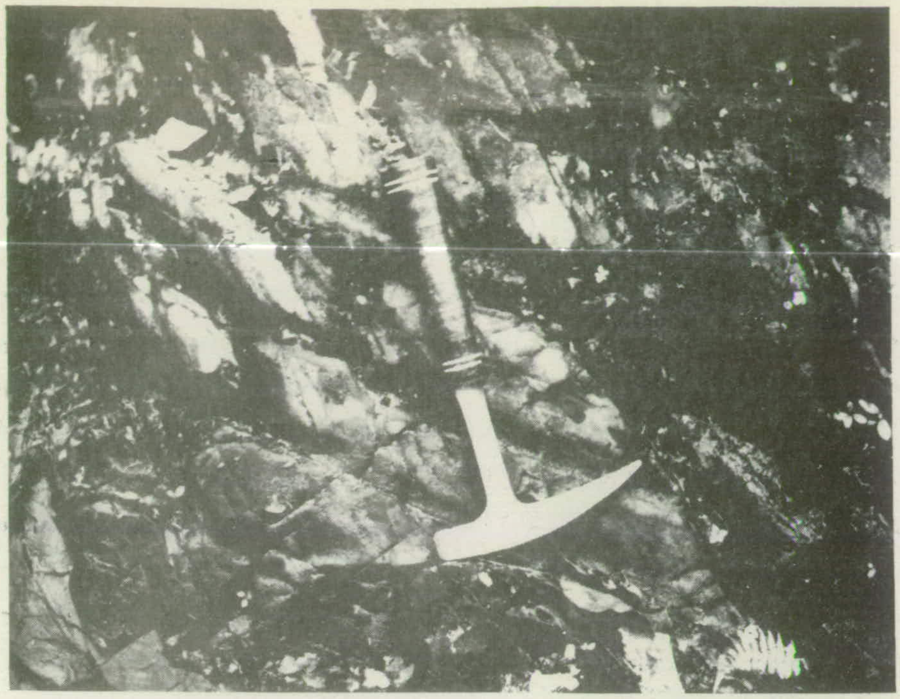

Figure 14. Fracture cleavage at a high angle to bedding in slate of the Kemum Formation in the lower reaches of the Wariki River.

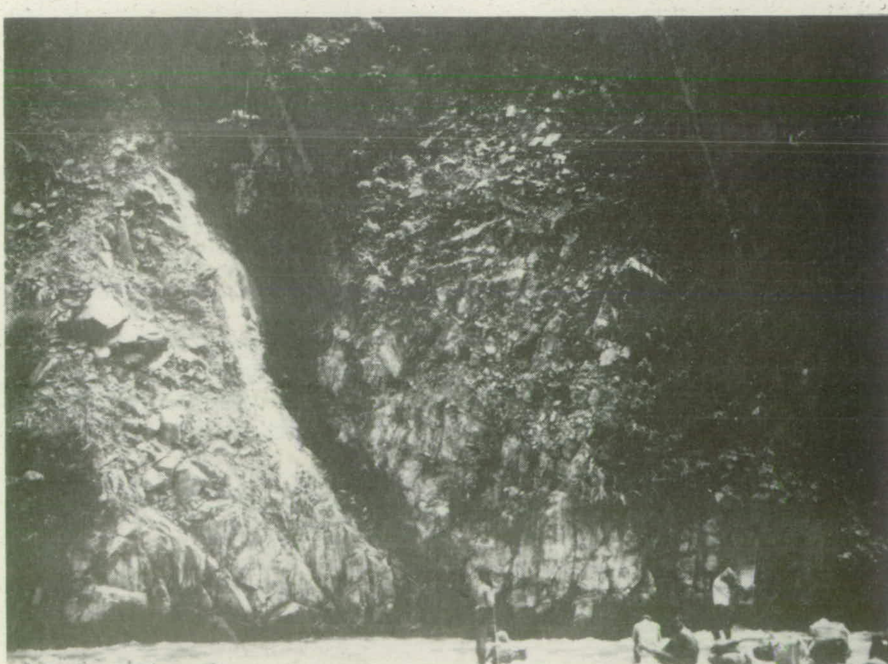

Figure 15. Normal fault with curved fault plane in metagreywacke sandstone of the Kemum Formation. Lower reaches of the Waryori River.

In the field the most interesting structures in the Manokwari Sheet area are those in the metamorphic rocks of the Kemum Formation. Brittle fracture is by far the most striking structural feature of these rocks (Fig. 12). Jointing and cleavage are well shown in many outcrops in the Waryori, Waramoi, and Ibarregah Rivers, mainly in quartzite, siliceous argillite, slate, and mica schist. Conjugate shear joints (Fig. 13) and fracture cleavage (Fig. 14) constitute the most common types of brittle fracture. The majority of joints occur in sets which cut across entire outcrops; nonsystematic joints are uncommon. Slatey cleavage is well shown in a few outcrops of calcareous slate in the Ibarregah River. Fine subparallel creases are present on some of the cleavage planes, and evidence of linear stretching appears on others. Small-scale folding is evident in a few outcrops in the Ibarregah River where pegmatite sills have been intruded into quartzite. The sills may have been folded as a result of nearby small-scale thrusting. Most faults seen in outcrop are thrusts, although a normal fault with curved fault plane and a drag flexure in the beds on the downthrown side cuts metagreywacke on the eastern bank of the Waryori River (Fig. 15). The Wariki Granodiorite is not as intensely jointed as the surrounding Kemum Formation, although it shows evidence of some shearing and folding after emplacement. The main period of deformation may have been in the Permian, immediately before intrusion. By contrast, the comparatively young middle Miocene Lembai Diorite is little-fractured. Schistosity is best developed in the Kemum Formation in the Ibarregah River where numerous pegmatite intrusions cut the unit and signify to the presence of the Wariki Granodiorite near the surface.

During Pleistocene uplift of the mountainous area in the southern part of the Sheet area, alluvium and fanglomerate became tilted to the north.

GEOLOGICAL HISTORY

A thick pile of fine-grained terrigenous mud or shale, bedded chert, and occasional fine-grained greywacke sandstone and siltstone was deposited in a deep-sea environment in Silurian-Devonian times. During the Permian these deposits were folded, faulted, and intruded by the Wariki Granodiorite. Either in the Late Cretaceous or early Eocene the Australian Plate began to move northwards and collided with the west-northwesterly moving Pacific Plate. The collision suture between the plates bent and ultimately ruptured as the Australian Plate bulged northwards into the Pacific Plate. The northeast part of the suture became the Ransiki Fault Zone and the southwest part became the Banda Arc. As a result of this plate interaction, an Oligocene to Miocene volcanic arc (Arfak Volcanics) developed on the northeastern side of the Ransiki Fault Zone. Coral reefs (Kais Formation) developed along the edge of this island arc in Miocene times. At the end of the Miocene, sinistral movements in northern Papua New Guinea and Irian Jaya (caused by the northwesterly movement of the Pacific Plate) forced Kepala Burung against the Banda Arc. This northwesterly movement, together with a possible northeasterly directed stress associated with a spreading centre in the Banda Sea, caused the clockwise rotation of Kepala Burung, with the result that the Ransiki Fault Zone assumed its present northwesterly trend.

In the early Miocene to Pliocene, the terrain consisting mainly of the Kemum Formation and Wariki Granodiorite was uplifted and marine and estuarine mud, silt, and sand (Befoor Formation) were laid down on the northern side of the emergent area. During this uplift the Lembai Diorite was intruded into the western edge of the island-arc environment near the Ransiki Fault Zone and explosive volcanic activity (Berangan Agglomerate) took place near the north coast. Uplift and associated tensional fracturing continued to the south - particularly in the Arfak Mountains to the southeast - throughout Pliocene and Pleistocene times. Fringing reefs (Manokwari Limestone) were successively uplifted throughout the Pleistocene. At the edge of the mountain front, coarse alluvium and fanglomerate accumulated during uplift, and subsequently became dissected and tilted to the north.

ECONOMIC GEOLOGY

No economic mineral deposits have yet been discovered in the Sheet area. Economically the area is of interest mainly as a source of construction materials, including deposits of limestone near Manokwari town.

Radioactive minerals

In 1959, 1961 and 1962 an economic geological investigation of northeastern Kepala Burung (d'Audretsch and others, 1966) revealed small radioactive anomalies - though probably not of economic significance - in some of the granite bodies just outside the Sheet area.

Limestone

Compact hard algal-foraminiferal biomicrite (Kais Formation) of high purity in the southeastern part of the Sheet area would probably be suitable for cement manufacture. Deposits of clay occur in the neighbouring Befoor Formation.

Construction materials

Gravel suitable for road-surfacing or concrete aggregate is abundant in the alluvial plains. Crushed Pleistocene limestone would be of use in surfacing roads and airstrips.

Hydroelectric potential

The area is suited to a number of small hydroelectric schemes. As the Kemum Formation is a competent unit, slope stability and underground leakage would probably not be serious problems in the mountainous southern part of the Sheet area. The granodiorite in the lower Waryori River would provide a sound foundation for a dam. Access to the dam site would not be difficult across the alluvial plain, and there would be a ready source of construction materials.

Groundwater

During normal weather, Manokwari town depends on water from bores and dug wells; rainwater catchment and storage tanks are not used extensively. Water-table aquifers are mainly of Pleistocene limestone.

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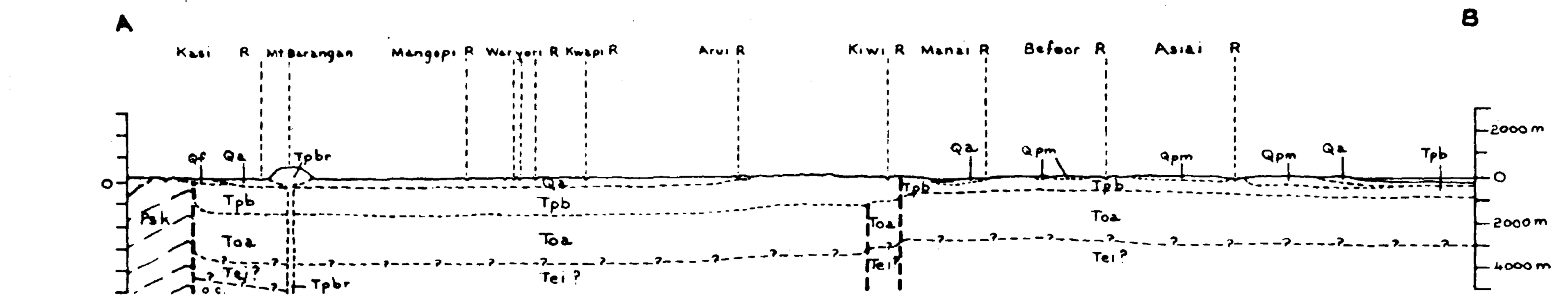
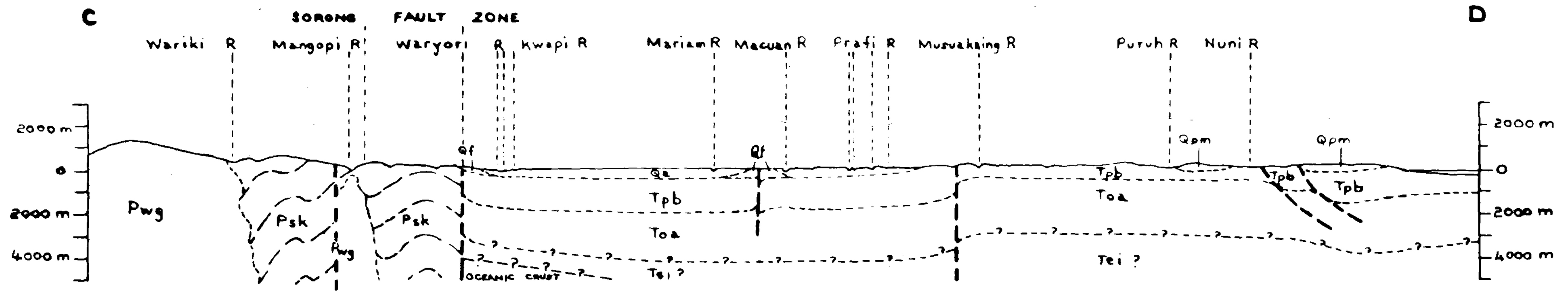
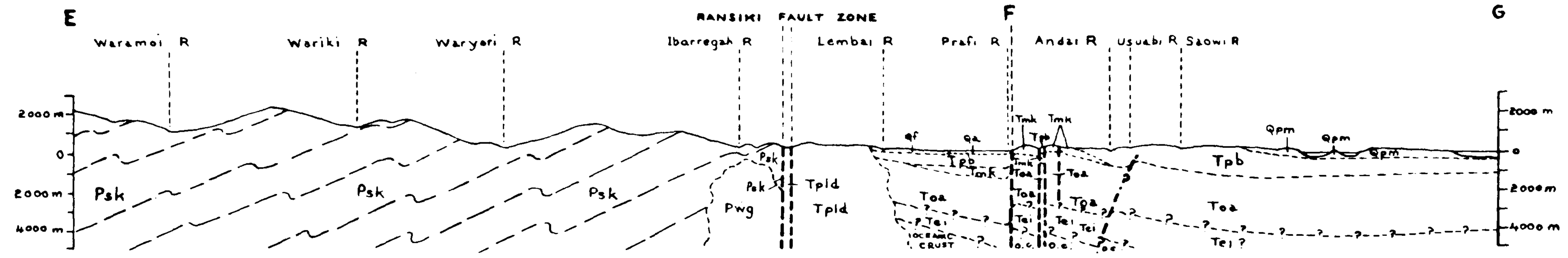






CAINOZOIC	QUATERNARY	PLEISTOCENE TO HOLOCENE		Qa	Coarse gravel, sand, fine silt, and mud; becomes finer towards the north. Most clasts are from Kemum Formation. River terraces in places; alluvium and beach deposits.
				Qf	Coarse alluvium and fanglomerate. Locally massive very poorly sorted conglomerate and boulder beds interbedded with well bedded dark yellowish orange clay.
		PLEISTOCENE	Manokwari Limestone	Qpm	Massive porous, resistant algal-foraminiferal biomicrite, calcirudite calcilutite and calcarenite; greyish yellow to white; heavily contaminated by terrigenous detritus in places.
	TERTIARY	LATE MIOCENE TO PLEISTOCENE (N17 – N22)	Befoor Formation	Tpb	Soft friable and porous sandstone, siltstone and mudstone. Well bedded, locally current lamination and large-scale cross bedding. Usually weakly calcareous. Mudstone strongly calcareous with planktonic forams. Rarely bivalves and calcarenite.
		PLIOCENE ?	Berangan Agglomerate	Tpbr	Basaltic to andesitic agglomerate; clasts of porphyritic, scoriaceous low-silica andesite with 2% plagioclase phenocrysts 3 mm long.
		MIDDLE MIOCENE (15·4 m.y.)	Lembai Diorite	Tpld	Medium dark grey and olive grey diorite, holocrystalline, coarse; locally grades into gabbro. Numerous acidic veins and dykes. At the contact zone Kemum Formation schist and phyllite shows various stages of complete replacement.
		EARLY TO MIDDLE MIOCENE (upper Te – Lower Tf)	Kais Formation	Tmk	Massive yellowish grey to white algal-foraminiferal biomicrite; resistant, non-porous and brittle; possibly fringing or barrier reef.
		OLIGOCENE ? to MIOCENE ?	Arfak Volcanics	Toa	Basalt and andesite flow breccia, tuff, rubble slides, paraconglomerate and turbidite deposits. Subaerial and submarine.
		LATE EOCENE TO MIDDLE MIOCENE	Imskin Formation (section only)	Tei	Well bedded, dense, reddish or light grey aphanitic limestone. Locally abundant pelagic Foraminifera. A few moderately resistant marl beds.
MESOZOIC		LATE PERMIAN TO MIDDLE TRIASSIC (222 – 246 my)	Wariki Granodiorite	Pwg	Granodiorite with planar fabric in places and very coarse light grey granite. Some pegmatite.
PALAEOZOIC		SILURIAN TO DEVONIAN	Kemum Formation	Psk	Black to medium grey slate, quartzite, siliceous argillite, metachert and phyllite in east; dark grey to black mica schist in west, locally with andalusite. Small-scale slumping in places; locally pyritic. A few metamorphosed micromonzonite dykes.

Geological boundary

Fault

Strike and dip of strata

Strike and dip of cleavage

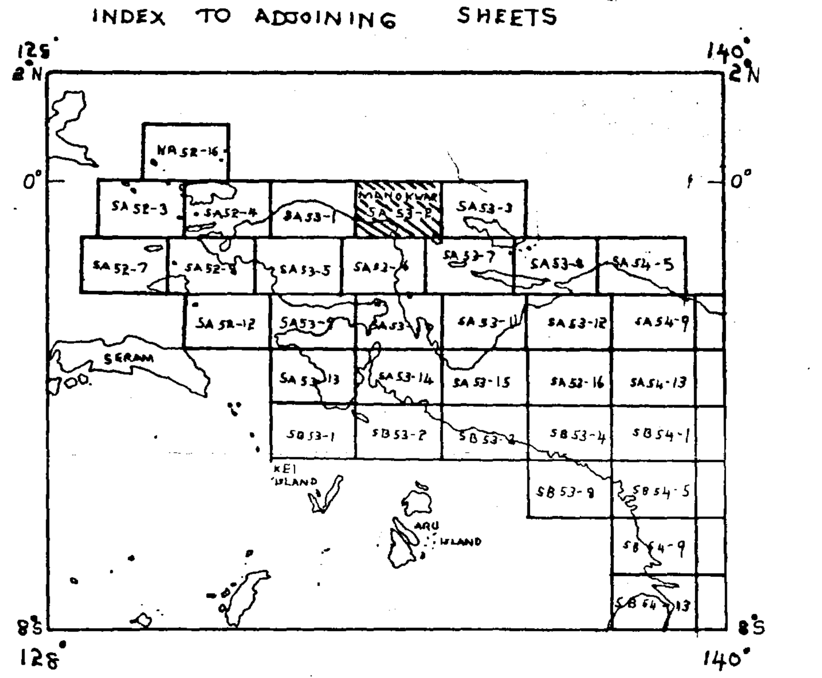
Dip < 5°

Dyke, pegmatite

Microfossil locality

Sample locality for isotopic age determination

INDEX TO ADJOINING SHEETS



Geology	1935 – 60	by Nederlandsche Nieuw Guinee Petroleum Maatschappij
	1959 – 62	by Stichting Geologisch Onderzoek Nederlands-Nieuw-Guinea
	1976	by G. P. Robinson, N. Ratman, D. S. Hutchison, M. Masria, D. S. Trail, H. Sumadirdja, P. E. Pieters and Kastowo.
Compiled	1976 – 7	by N. Ratman, M. Masria, G. P. Robinson, Kastowo

Cartography by

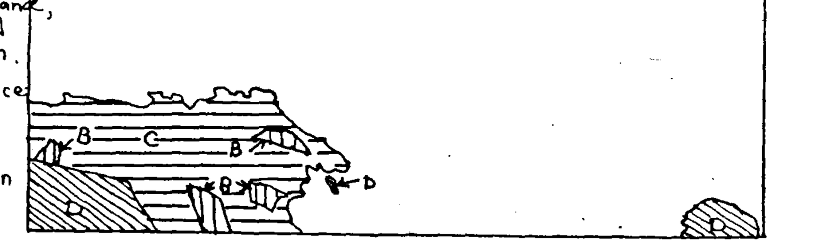
Drawn by

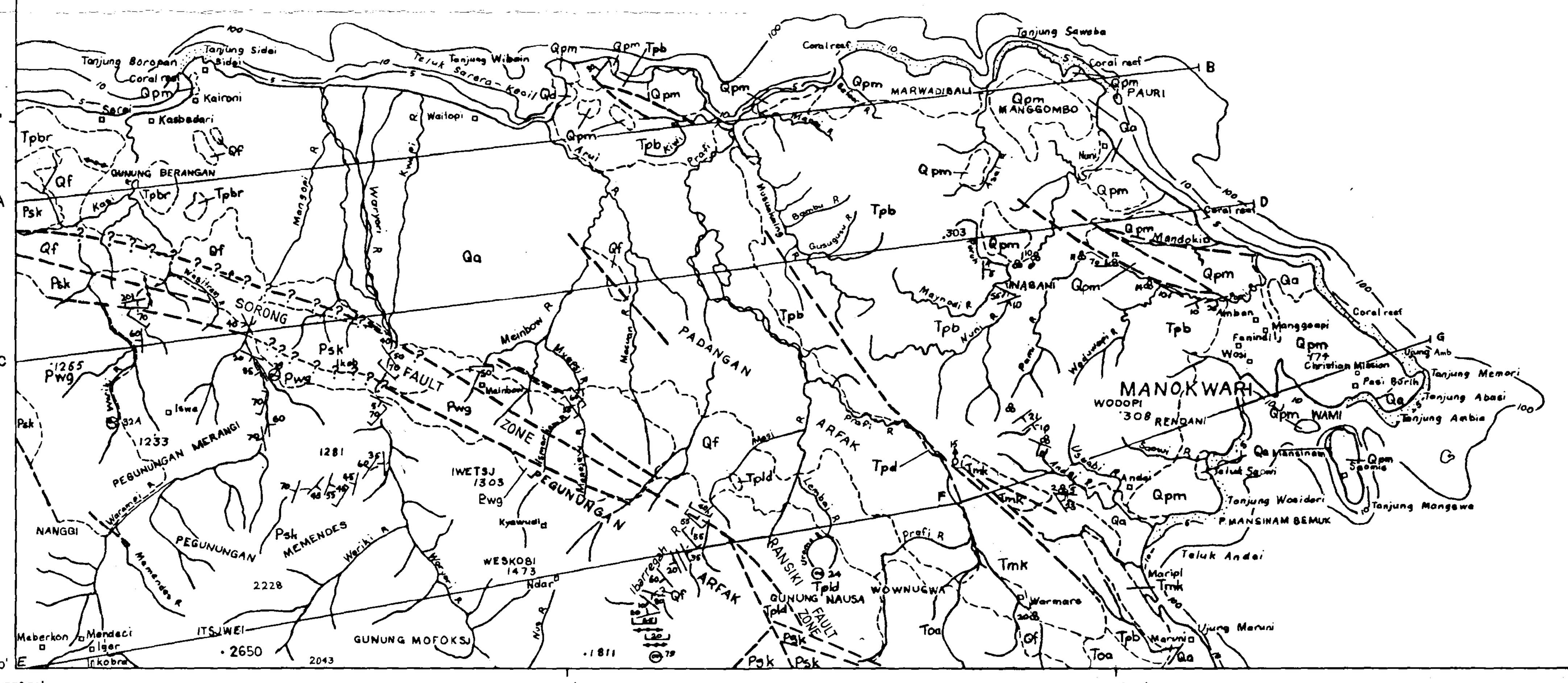
Geology

B Detailed reconnaissance, numerous traverses and airphoto interpretation.

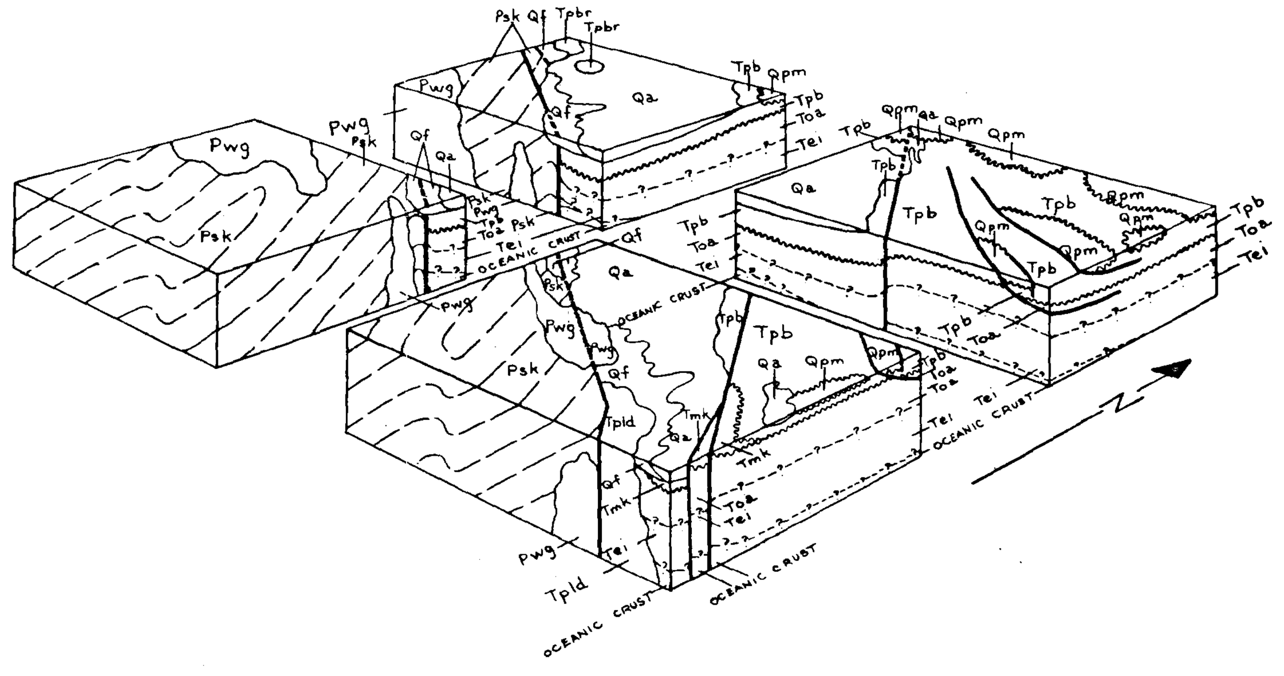
C General reconnaissance, some traverses and airphoto interpretation

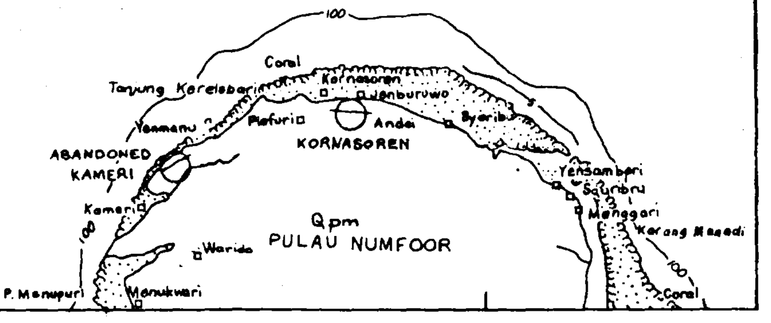
D Airphoto interpretation





ROCK RELATIONSHIP DIAGRAM





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APPENDIX II: MICROPALAEONTOLOGY

Micropalaeontological data have been assembled from typed manuscripts by D.J. Belford and G.C. Chaproniere (BMR) and Dra Purnamaningsih (GSI). All specimens have the BMR project number 76629. Locality numbers refer to the geological map. Early Tc, Tf, etc. are ages of the East Indies Tertiary letter stages, and N17-22 are Neogene planktonic foraminiferal zones (Appendix I).

All specimens were collected from outcrop except 77629016 taken from a boulder which had probably not been transported far.

Details of the microfaunas for some of the above samples from the summary by Dra Purnamaningsih are set out below. These assemblages indicate an open marine sublittoral to bathyal environment of deposition.

Locality No. 10, specimen No. 013 (Befoor Formation)

Planktonic foraminifera: *Globorotalia truncatulinoides* (d'Orbigny); *Pulleniatina obliquilculata* (Parker and Jones); *Globorotalia tumida* (Brady); *Globigerinoides ruber* d'Orbigny; *Globigerinoides conglobatus* (Brady); *Hastigerina siphonifera* d'Orbigny; *Globorotalia humerosa* Takayanagi and Saito; *Globigerinoides sacculifer* (Brady): *Globorotalia tosaensis* Takayanagi and Saito; *Orbulina universa* d'Orbigny; *Globorotalia menardii* (d'Orbigny); *Globorotalia crassaformis* (Galloway and Wissler); *Pulleniatina promalis* Banner and Blow. Smaller benthonic foraminifera: *Uvigerina* spp.; *Nodosaria* sp.; *Bolivina* sp.; *Bulimina* sp.; *Triloculina* sp.

Locality No. 11, specimen No. 014 (Befoor Formation)

Planktonic foraminifera: *Pulleniatina obliqueloculata* (Parker and Jones); *Sphaeroidinella dehiscens* (Parker and Jones); *Globigerina conglobatus* (Brady); *Globorotalia tosaensis* Takayanagi and Saito; *Globorotalia*

CAINOZOIC TIME SCALE

ADAMS 1970 — CLARKE AND BLOW 1969, BLOW 1969 — RADIOMETRIC TIME SCALE

Epoch (Adams 1970)	Tertiary Letter Stage (Adams 1970)	Planktonic Foram Zone	Tertiary Letter Stage	Epoch	m.y.
Pleistocene	Th	N23, N22		Pleistocene	Pliest / Plio 1·85
Pliocene	Th	N21, N20, N19	? ? Th	Pliocene	Plio / Mio 5 5
upper Miocene	Tg	N18, N17, N16	Tg	late Miocene	Tg / Tf 9
upper Miocene	upper Tf ($\equiv f_3$)	N15, N14, N13	upper Tf ($\equiv f_3$)	middle Miocene	upper Tf / lower Tf 12·5
middle Miocene	lower Tf ($\equiv f_{1-2}$)	N12, N11, N10, N9	lower Tf ($\equiv f_{1-2}$)	middle Miocene	lower Tf / upper Te 15
Lower Miocene	upper Te ($\equiv e_5$)	N8, N7, N6, N5, N4	upper Te ($\equiv e_5$)	early Miocene	Mio. / Olig 22·5
upper Oligocene	lower Te ($\equiv e_{1-4}$)	N3, N2, N1	lower Te ($\equiv e_{1-4}$)	Oligocene	u Olig / m Olig 30
middle Oligocene	Td	P19 ↑	Td	Oligocene	m Olig / l Olig 32
lower Oligocene	Tc	P18	Tc	Oligocene	Olig / Eo 36
upper Eocene	Tb	P17, P16, P15	Tb	late Eocene	u Eo / m Eo 45
		P14	? ?	? ? ?	
middle Eocene	Ta_3				m Eo / l Eo 49
lower Eocene	Ta_2				Eo / Paleo 53·7
? ? ? upper Paleocene	Ta_1				uPaleo / l Paleo 60; Paleo / Cret 65

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Locality No.	Specimen no. (BMR)	Age	Rock type
2	002	late Pliocene-Pleistocene (N21-N22)	siltstone
3	008	early-middle Pliocene (N19-N21)	sandstone
5	009	late Miocene-middle Pliocene (N17-N20)	silty mudstone
9	011	late Miocene-middle Pliocene (N17-N20)	very fine sandstone
10	013	late Pliocene-Pleistocene (N21-N22)	silty mudstone
11	014	late Pliocene-Pleistocene (N21-N22)	silty mudstone
12	015	late Pliocene-Pleistocene (N21-N22)	silty mudstone
14	016	Pleistocene or younger	algal-foraminiferal biomicrite
20	0020	early-middle Miocene (late Te-early Tf)	algal-foraminiferal biomicrite

truncatulinoides (d'Orbigny); *Globigerinoides ruber* d'Orbigny; *Hastigerina siphonifera* d'Orbigny; *Globorotalia acostaensis* Blow; *Globorotalia menardii* (d'Orbigny); *Globorotalia tumida* (Brady); *Globigerinoides sacculifer* (Brady). Smaller benthonic foraminifera include: *Uvigerina hispida* Schwager; *Laticarinina pauperata* (Parker and Jones); *Pyrgo* sp; *Nodosaria* sp.; *Dentalina* sp.; *Robulus* sp.

Locality No. 12, specimen No. 015 (Befoor Formation)

Planktonic foraminifera: *Globorotalia truncatulinoides* (d'Orbigny); *Globorotalia tosaensis* Takayanagi and Saito; *Pulleniatina obliqueloculata* (Parker and Jones); *Globorotalia menardii* (d'Orbigny); *Hastigerina aequilateralis* (Brady); *Globigerina calida* Parker; *Globigerinoides ruber* d'Orbigny; *Globorotalia tumida* (Brady); *Globigerinoides sacculifer* (Brady); *Globigerinoides conglobatus* (Brady); *Hastigerina siphonifera* d'Orbigny; *Orbulina universa* d'Orbigny. Smaller benthonic foraminifera include: *Eponides* sp.; *Uvigerina* spp.; *Bolivina* sp.; *Nodosaria* sp.; *Robulus* sp.; *Gyroidina* sp.; *Bulimina* sp.

APPENDIX III: K-AR AGE DETERMINATIONS

K-Ar analyses of three samples from the Wariki Granodiorite indicate ages ranging from Late Permian to Middle Triassic. Details of these analyses are as follows:

Analyst: AMDEL (Report AN 2/1/10 - 2527/77)

Constants used : $K^{40} = 0.0119$ atom%

$\lambda_\beta = 4.72 \times 10^{-10}\ yr^{-1}$

$\lambda_e = 0.584 \times 10^{-10}\ yr^{-1}$

BMR sample no.	Field no.	K%	Ar^{40}/K^{40}	% atm.Ar	Age ($x10^6$ y)
76629110 Muscovite	RO 79	8.88,8.94	0.014532	2.5	234 ± 4
76629110 Biotite	RO 79	6.25,6.20	0.014230	1.8	229 ± 4
76629041 Biotite	RO 39	4.64,4.63	0.013740	2.8	222 ± 4
766299035 Biotite	RO 32A	6.90,6.94	0.015342	1.4	246 ± 4

A K-Ar analysis of a sample from the Lembai Diorite indicates a middle Miocene age. Details of this analysis are as follows: Analyst and constants as above.

BMR sample no.	Field no.	K%	Ar^{40}/K^{40}	%atm.Ar	Age ($x10^6$ y)
76629026	RO 24	0.191,0.192	0.00090587	76.7	15.4 ± 0,5